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Preliminary Results from P78-2 Satellite

J. F. FENNELL and D. R. CROLEY, JR.
Laboratory Operations
The Aerospace Corporation
El Segundo, Calif. 90245

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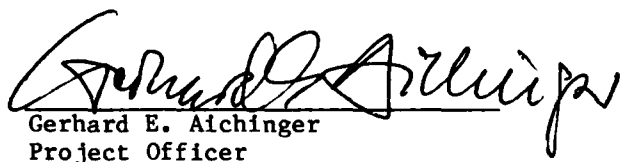
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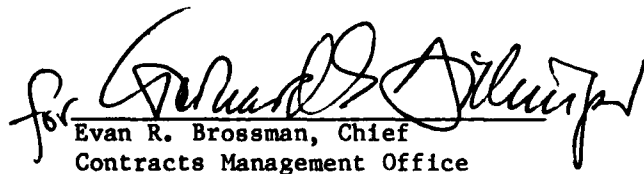
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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.


Gerhard E. Aichinger
Project Officer

FOR THE COMMANDER


for Evan R. Brossman, Chief
Contracts Management Office

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Several particle instruments and a pair of spherical probes on three meter booms, built by The Aerospace Laboratories are in orbit aboard the P78-2 spacecraft. The experiments are briefly described and several examples of preliminary observations are presented and discussed. The probe measurements have shown that the P78-2 spacecraft frame potential changes as it rotates because the area of the illuminated grounded conductors varies as different portions of the spacecraft become sunlit. The probes have also			

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measured the spacecraft potential during several onboard accelerator operations. The particle analyzers have observed the acceleration of the ambient plasma during artificially induced spacecraft charging events. The particle experiments have also measured the natural environment. One set of observations shows the occurrence of field aligned ions at energies of a few hundred eV/q. The angular distributions of these ions peak near 0° and 180° in pitch angle. These and other observations will be discussed.

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Introduction

The P78-2 satellite was launched on 30 January 1979 by Air Force Space Test Program. The satellite was inserted into its final orbit on 2 February. The final orbit has an apogee of about 43200 km ($L \sim 7.8 R_e$), perigee of ~ 27500 km ($L \sim 5.3 R_e$) and an inclination of ~ 7.8 deg. The apogee and perigee points are near the geographic equator. The orbit has a period of ~ 23.6 hrs and thus the mean position of the satellite drifts eastward at $\sim 5.4^\circ$ per day. On 5 February apogee was at $\sim 190^\circ$ east longitude.

The spacecraft is spin stabilized (spin rate ~ 1 rpm) with the spin axis in the orbit plane and maintained approximately perpendicular to the satellite-sun line. This allows those experiments which have view axes that are perpendicular to the spin axis to scan a large range of angles relative to the magnetic field. It also allows many experiments on the end of the spacecraft to be in shadow (or sunlight) for extended periods and for others to rotate through the spacecraft shadow.

The data obtained through February contains many ambient magnetospheric observations and several sets of measurements taken during active experiments when the on board ion accelerator was used to induce a charge on the spacecraft. To date only "quick look" listings, made at the satellite control center, are generally available for analysis. These listings cover only limited time periods and do not contain the full instrumental outputs so that the data presented below is not complete.

A description of the satellite and the complete instrument compliment is available (Stevens and Vampola, 1978) and should be referred to for such details.

Experiment Description

The SC2 experiment consists of electrostatic analyzers mounted on the spacecraft (SC2-3E) in the conducting center band and in the spherical probes (SC2-1 and SC2-2) at three meters from the spacecraft (ref. Stevens and Vampola, 1978) plus an energetic proton telescope (SC2-6) and an energetic heavy ion telescope (SC2-3B) which are also in the center band (see Figure 1). The view directions of all the particle experiments are perpendicular to the spin axis and approximately parallel to each other.

The electrostatic analyzers measure electrons and ions in the energy per charge range of ~ 5 to 186000 ev/q as shown in Table 1. A complete spectrum is normally obtained every three seconds. The programs can be interlaced or run separately to trade off angular resolution for a detailed energy spectrum. The analyzer programs can also be slowed down so that 512 seconds are required to obtain a spectrum but the angular resolution at a given energy is increased to about one degree in angular scan per sample. Each sample is accumulated over ~ 101 msec and the normal stepping rate of the units is eight steps per second. The geometric factors and approximate angular and energy responses for the analyzers are included in Table 1.

The potential that the Aqua-dag coated spherical probes (SC2-1 and SC2-2) attain relative to the spacecraft is measured once each second. The sensitivity of the measurement (common mode voltage only) covers the range $\pm .02$ to ± 700 volts. As will be seen the probes can be used to obtain vehicle potential variations with relatively high time resolution. The probes can be biased, using an internal supply, to voltages ranging from 0 to ± 20 volts or 0 to ± 450 volts in 32 logarithmically spaced steps. The current to the SC2-1 probe is measured when it is being biased. The electrometer measures currents from $\pm 10^{-14}$ to $\pm 10^{-7} \text{ amps/cm}^2$. Biasing the probes modifies the spacecraft plasma-sheath fields and the trajectories of the particles therein. In fact, when biased

Table 1
SC2 - Electrostatic Analyzer Energies

Step		Energy* (ev/charge)	
		Electrons	Ions
Program 1	0	183	150
	1	425	360
	2	1060	900
	3	2530	2110
	4	4420	3700
	5	10600	9000
	6	18800	15800
	7	Return to zero	Return to zero
Program 2	0	0.0 - 5	0.0 - 4
	1	88	77
	2	313	260
	3	790	670
	4	1900	1590
	5	5720	4850
	6	14100	11900
	7	Return to zero	Return to zero
Program 3	0	6 - 13	5 - 11
	1	17 - 25	15 - 24
	2	43	38
	3	590	500
	4	1420	1200
	5	3350	2790
	6	7970	6730
	7	Return to zero	Return to zero
Geometric Factor		$\sim 9^\circ \times 10^{-4} \text{ cm}^2 \text{ ster}$	$\sim 6.5 \times 10^{-4} \text{ cm}^2 \text{ ster}$
Angular Response [#]		$\sim 9^\circ \times 7^\circ$	$\sim 16^\circ \times 9^\circ$
Energy Response		$\Delta E/E \sim 7\%$	$\Delta E/E \sim 8\%$

* Energies vary $\sim 5\%$ between the three units

[#] At full width at 10% of maximum response.

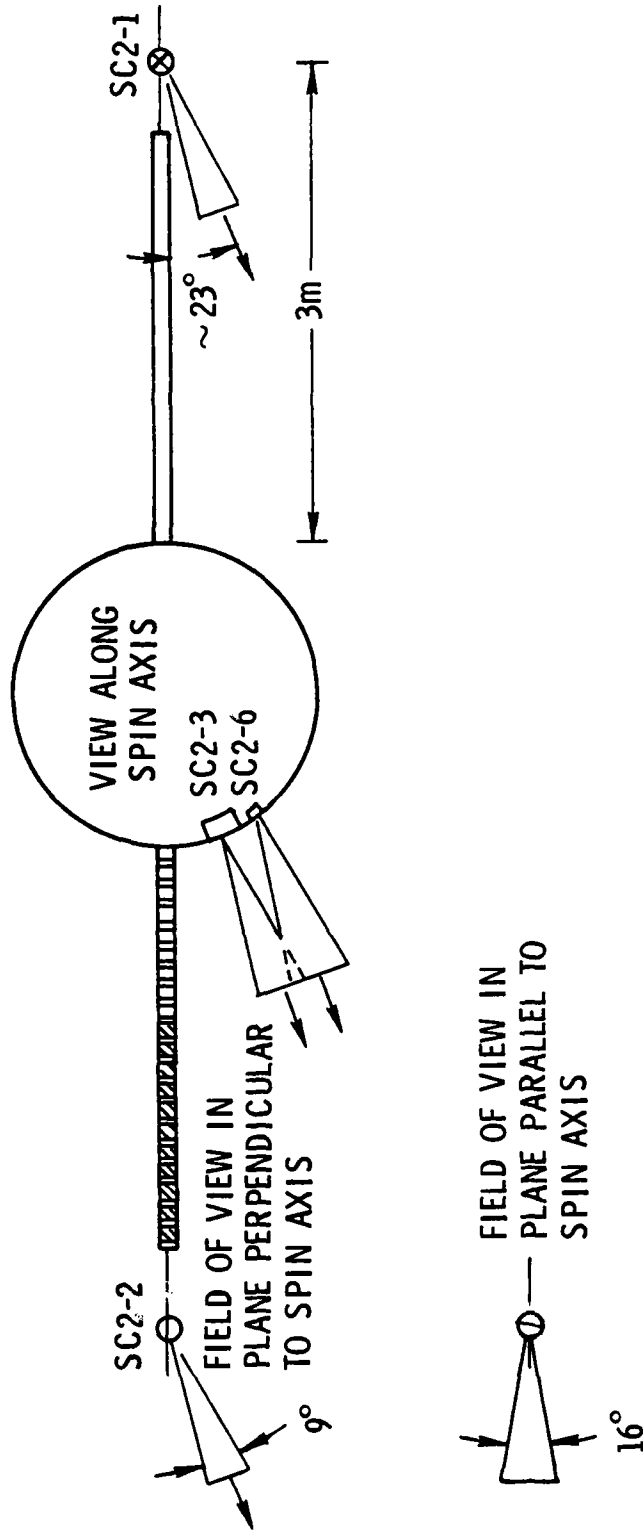


Fig. 1. Relative Positions of SC2 Experiments on Spacecraft with Their Fields of View
 [The view is with the spin axis pointing out of the page. Spacecraft rotation would be counterclockwise in this view. All figures taken from Stevens and Vampola (1978)]

positively the probes draw the photoelectrons from the spacecraft photosheath so that they are no longer measured by the low energy particle detectors on the spacecraft (DeForest, private communication; 1979). When the probes are biased negatively the ambient ions are accelerated to them and into the electrostatic analyzers interior to the probe. This allows an estimate of the ion density to be made.

The energetic proton detector (SC2-6) is a two element solid state detector telescope. The collimator contains a broom magnet to eliminate electrons from the measurement. The energies measured and the geometric factor are shown in Table 2. Each energy is measured once per second. With the large geometric factor and large $\Delta E/E$ this detector usually obtains good counting statistics in a single sample.

The heavy ion detector (SC2-3B) is also a two element solid state detector telescope. The front detector is very thin (~ 2.4 microns) and small ($\sim 10 \text{ mm}^2$) so that it is insensitive to energetic electrons and high energy protons ($E_p \geq 280 \text{ keV}$). The telescope is very well collimated. There is a collimator in front of a broom magnet (removes all electrons $\leq 1 \text{ MeV}$ from particle beam) and another collimator between the magnet and the detector housing. The detector housing is made of thick brass which should stop $< 45 \text{ MeV}$ protons and $< 5 \text{ MeV}$ electrons. This shielding combined with the veto detector (second detector), the electron broom magnet and the very thin front detector combine to give a very clean ion measurement. Because of the small detector size and tight collimation the geometric factor is small (see Table 3). This requires that many minutes of data be averaged in order to obtain an angular distribution. We have not included any heavy ion data in this report but include the instrument parameters for completeness. The particle energies measured, angular response, and the geometric factor are given in Table 3. Most of the channels are sampled once per second. The α_1 and CNO_1 channels are also sampled four times per second to obtain increased angular resolution. The ion detector data will be reported when enough tapes are available to obtain good counting statistics.

Table 2
Energy Channels for Energetic Proton Detector SC2-6

Channel	Energy [#] (keV)
P1S [*]	14 - 24
P2	24 - 48
P3	48 - 94
P4	94 - 172
P5	172 - 352
P6	352 - 700
P7	700 - 3300
P2S	3300

Geometric Factor $\sim 2 \times 10^{-3} \text{ cm}^2 \text{ ster}$

Angular Response $\sim 9^\circ \text{ FWHM}$

[#] Defined at half response points for -2° C . Channels are temperature sensitive.

^{*} Efficiency of this channel is $\sim 90\%$.

Table 3
Energy Channels for Energetic Heavy Ion Detector

Channel	Energy
BP1S	$\begin{cases} E_p > 125 \text{ keV} \\ E_{\alpha, \text{CNO}} < 390 \text{ keV} \end{cases}$
α_1	$390 \leq E_{\alpha} \leq 960 \text{ keV}$
α_2	$550 \leq E_{\alpha} \leq 960 \text{ keV}$
CNO ₁	$1.21 \leq E_{\text{CNO}} \leq 2.7 \text{ MeV}$
CNO ₂	$1.48 \leq E_{\text{CNO}} \leq 2.7 \text{ MeV}$
CNO ₃	$1.77 \leq E_{\text{CNO}} \leq 2.7 \text{ MeV}$
> CNO	$E_{\text{CNO}} > 5.4 \text{ MeV}$
BP2S	$\begin{cases} E_p > 390 \text{ keV} \\ E_{\alpha} > 960 \text{ keV} \\ E_{\text{CNO}} > 2.7 \text{ MeV} \end{cases}$
2B	$\begin{cases} E_{\alpha} > 3.8 \text{ MeV} \\ E_{\text{CNO}} > 6.5 \text{ MeV} \end{cases}$

Geometric Factor $\sim 3.6 \times 10^{-4} \text{ cm}^2 \text{ ster}$

Angular Response $\sim 4^\circ \text{ FWHM}$

Results and Discussion

Several observations are presented below which give some idea of the kinds of data that are available from the Aerospace SC2 instruments on P78-2. These are not all the kinds of phenomena which have been observed but are those which are, for the most part, unique to the P78-2 set of observations.

Figure 2 shows a sample of the raw SC2-1 and SC2-2 probe voltage outputs for about two spin periods. The points at which the probes pass through the spacecraft shadow are noted as are the regions where the probe shadows its own boom and the shadow stub casts an asymmetric shadow on the probe. Since vehicle attitude is not yet available a detailed analysis of the shadows cannot be made. The decreases in probe voltage are a result of changing photo current at the booms and probe or zero photo emission from the probe, during eclipse by the satellite. The quick look data processing which uses very simple reduction algorithms provided this data. The algorithms cause small differences between the probes for identical relative orientations. Some of the differences are probably real and are a result of the inability to make the spheres exactly identical in all their surface properties.

As is shown in Figure 2 the probes are usually about 0.8 to 1.0 volt positive with respect to the spacecraft when they are in sunlight and probe 2 (SC2-2, see Figure 1) is rotating out of the vehicle shadow (perpendicular to the sun line and antiparallel to the orbit normal, i.e. SC2-2 is "South" of the vehicle) as occurs at 57880 - 57890 sec and 57934 - 57944 sec. This is to be compared to the periods (57905 - 57915 sec and 57958 - 57968 sec) when probe 1 (SC2-1, see Figure 1) is rotating out of the spacecraft shadow. Here the probe voltages initially approach the 0.8 to 1.0 volt values and then decrease together towards a relatively constant value of -0.04 to -0.1 volts (see 57860 - 57866 and

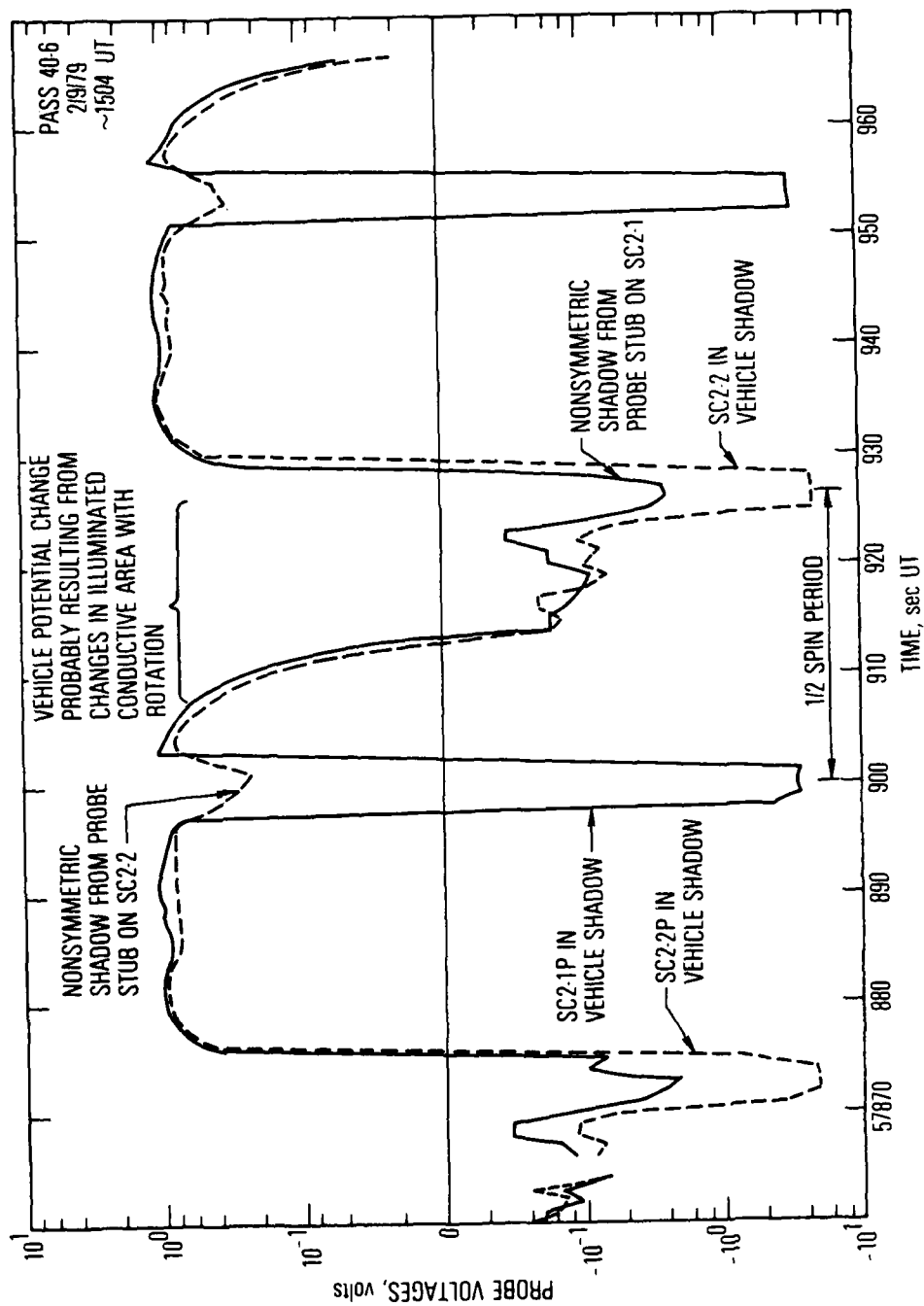


Fig. 2. SC2-1 and SC2-2 Probe Voltages Relative to Spacecraft Ground for About Two Spin Periods

57914 - 57920 in Figure 2) as the rotation continues. At time 57913 sec, for example, the line between SC2-1 and SC2-2 is perpendicular to the satellite sun line with SC2-1 south of the orbit plane. This orientation is the mirror image of the orientation at 57887 sec where SC2-1 is north of the orbit plane and the line between the probes is perpendicular to the sun line. The probe shadowing is the same in both orientations and one would expect the probe voltages to also be the same. The only thing different is that a different side of the cylindrical spacecraft is now sunlit.

Examination of the spacecraft construction (ref. Fig. 2.3 in Stevens and Vampola, 1978) shows that the two halves (relative to the line between SC2-1 and SC2-2) have different amounts of exposed conductor. This is a result of experiment requirements for conductors around apertures and the need for good thermal emitters (i.e. dielectrics) to maintain proper spacecraft temperatures. The deployment of the different materials around the vehicle gives rise to a larger conductive area on one side of the vehicle than the other. When exposed to the sun the photoemission from the larger conductive area will drive the spacecraft more positive than it was when the smaller area was sunlit.

Assuming the probe potentials relative to the plasma are the same, in both orientations where the line between the probes are perpendicular to the sun line, then a positive increase in the spacecraft potential relative to the plasma will appear as a decrease in the probe potential relative to the spacecraft. This assumption leads to the conclusion that the spacecraft potential had increased by ~ 1.4 volts at 57913 and 57967 sec. This result has been confirmed by examining the thermal ion fluxes (from SC7) and their distribution as a function of time. The thermal ions are retarded by an amount consistent with a vehicle potential of about 1 volt when the vehicle orientation is the same as when the probes show the potential change (D. Reasoner, private communication, 1979).

Another example of the probe data is shown in Figure 3. During the time this data was taken the spacecraft was being charged negative by using the ion accelerator (SC4-2) to emit ~ 1.1 keV ions (for a description of the accelerator see Stevens and Vampola, 1978). Since the SC2-1 and SC2-2 are isolated from the satellite (by $\geq 10^{12}$ ohms) their potential relative to the plasma is determined by photoemission, secondary emission and plasma current to the probes. Analysis of the particle distributions measured by the particle analyzers inside the probes indicates they are not charged to more than 20 volts relative to the plasma and are consistent with a few volts positive relative to the plasma. Thus, the large positive voltage measured during the artificial charging event means the satellite is being charged negatively to about -350 to -400 volts from 12980 -13030 sec UT. This we call the satellite's potential V_s relative to the plasma. These values of V_s are in agreement with the particle distributions measured on the spacecraft by the SC2-3 and SC9 (DeForest, private communication) particle analyzers.

The ion spectra measured on the satellite show a peak in their energy spectrum at 350 - 400 volts. This peak has been interpreted (DeForest, 1972) as resulting from the acceleration of the cold plasma ions to the negatively charged spacecraft. The ions arrive with energies at least equal to V_s . Thus, all ions with energies originally small compared to V_s are accelerated to energies of or slightly higher than V_s . This essentially causes all the cold ions to show up in a particle analyzer in only a few channels i.e., a "charging peak". The resultant flux peak represents, in essence, an integration of the plasma ion fluxes from zero to V_s in energy.

At time 13032 sec UT the ion current from the accelerator decreased rapidly (G. Mullen, private communication, 1979). The satellite response was to become momentarily more negative and then as the ion beam current dropped further towards zero the spacecraft slowly discharged until its potential approached its normal equilibrium

P78-2 SATELLITE
 SC2-1,2 PROBE VOLTAGES
 2 ma XENON IONS EMITTED
 AT ~1.1 keV

FEBRUARY 15, 1979
 0336-0353 UT

• SC2-1
 x SC2-2

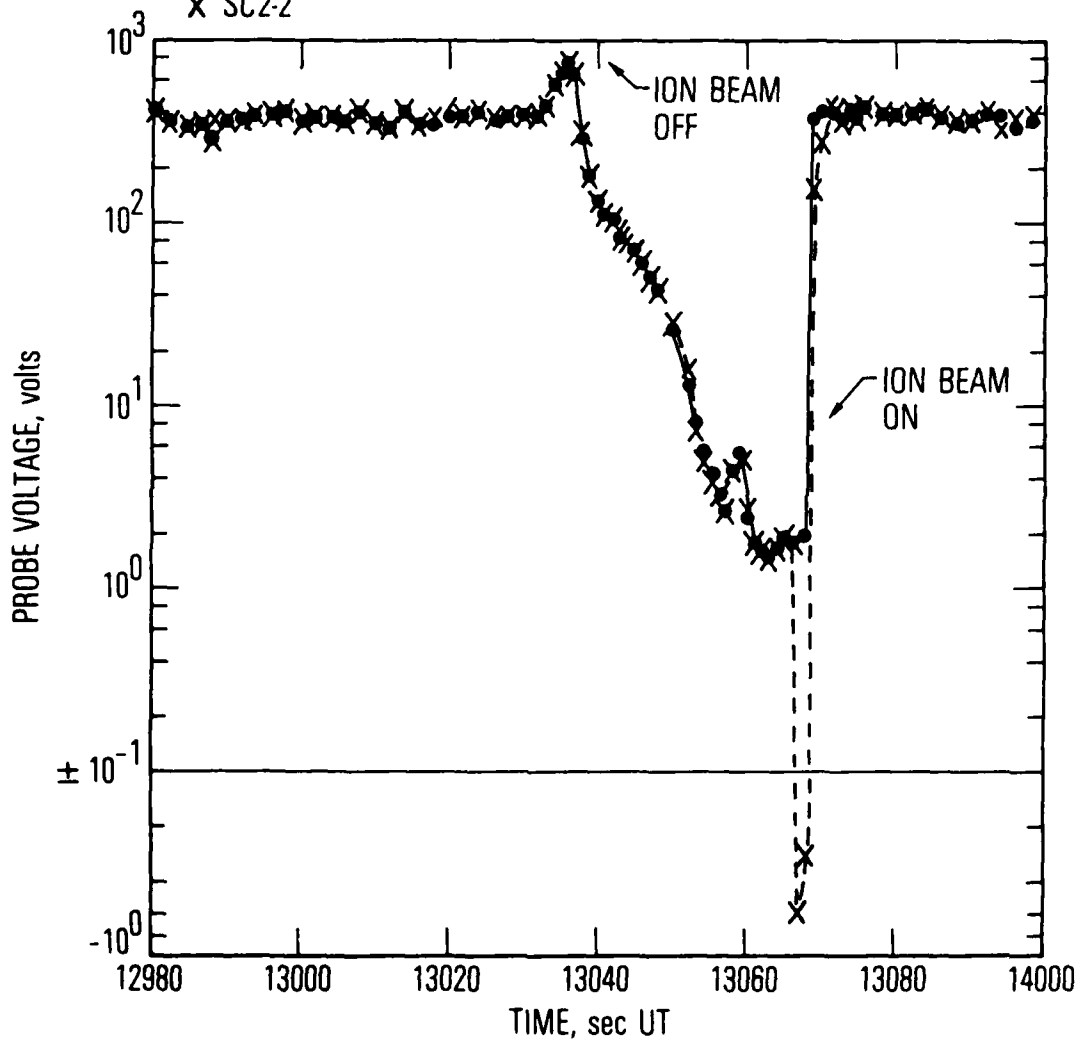


Fig. 3. SC2 Probe Voltages During an Artificial Charging Event.
 (The • points are from SC2-1 and the x points are from
 SC2-2. The annotations point out specific features.)

potential relative to the plasma near 13062 sec UT. The ion beam was restarted at 13068 sec UT and the spacecraft potential immediately returned to the same -350 to -400 volts it had attained earlier. This temporary increase in spacecraft potential as the ion beam current is decreased has been observed several times. One possible explanation is that when the full ~ 2 ma of ions is emitted from the ion gun the space charge effect causes the ion beam to expand in diameter and to "stall". This allows much of the ion current to be returned locally to the spacecraft frame ground. The remaining ion current is balanced by ambient ions plus photo and secondary electrons emitted by the spacecraft. When the emitted ion current is decreased the space charge in the beam is much reduced and more beam current actually gets away from the spacecraft causing it to be driven more negative. It has been found that under the proper plasma conditions that a 300 μ amp beam of ions is all that is required to drive the vehicle negative to a potential equal to the beam energy in sunlight. (The above description of the ion beam efficiency for charging a spacecraft has been provided by H. Cohen of the Air Force Geophysics Laboratory, the principal investigator for the SC4 accelerator system, and has been separately described to the author by D. Hall of The Aerospace Corporation; 1979.)

It suffices to say that the SC2-1 and SC2-2 probes can and have provided the spacecraft potential V_s during many of the artificial charging events. Unfortunately, the probe voltage measurement failed during one such event on March 31, 1979. The failure has been preliminarily ascribed to discharges which simultaneously occurred on the spacecraft. The actual mechanism of the failure is not known and is under investigation at the present time. Approximately 30 artificial charging events were carried out and several natural charging events were known to have occurred prior to the failures of the probe voltage measuring circuitry.

Another feature of the SC2-1 and SC2-2 probes is shown in Figures 4 and 5. The probes can be biased to voltages ranging from 0 to $\sim \pm 450$ volts (some control of probe bias remains after 31 March 1979) relative to the spacecraft. Figure 4 shows crude energy flux spectra (not all channels were available for the particle analyzers in the "quick look" data) of ions and electrons as measured at the probes (SC2-1, SC2-2) and at the spacecraft (SC2-3). The probes were biased to $\sim + 460$ volts relative to the spacecraft. This accelerated electrons to the probes (as shown by the electron curves labeled by SC2-1 and SC2-2) as compared to the unaccelerated fluxes measured at the spacecraft (electron curve labeled SC2-3). The electrons accelerated to the probes ($E_e < 460$ eV) are very intense, much more intense than the low energy fluxes observed at the spacecraft. This is most likely a result of accelerating photoelectrons from the spacecraft out to the probes. In fact, at this time the current to the SC2-1 probe was $-80 \mu\text{amps}$ (or $\sim -80 \times 10^{-9}$ amps/cm²). There were little or no ions below 2 keV in energy. The few counts (the ion flux of 50 corresponds to ~ 5 counts/sample in Figures 4 and 5) observed at low ion energies are consistent with background plus a slight response of the ion channels to electrons (response is $< 10^{-4}$ ion counts per electron). Thus, little effect is observed in the ions.

Figure 5 shows the effect observed when the probes are biased negatively to about -430 volts. The ambient ions are accelerated to the probes and are observed as a peak in the SC2-1 and SC2-2 ion spectra at ~ 430 volts with an intensity from 55 to ~ 140 times that observed at the spacecraft by SC2-3 at the same energy. Note also that the electron fluxes below 500 eV are much depressed relative to those observed at the spacecraft. This indicates that the low energy ambient electrons plus the photoelectrons from the probes have been repelled by them. An integration over the ion spikes from the probes can be used to give an estimate of the ambient cold-ion density. We have not done so for this case because data from all instrument energy channels are not yet available to us.

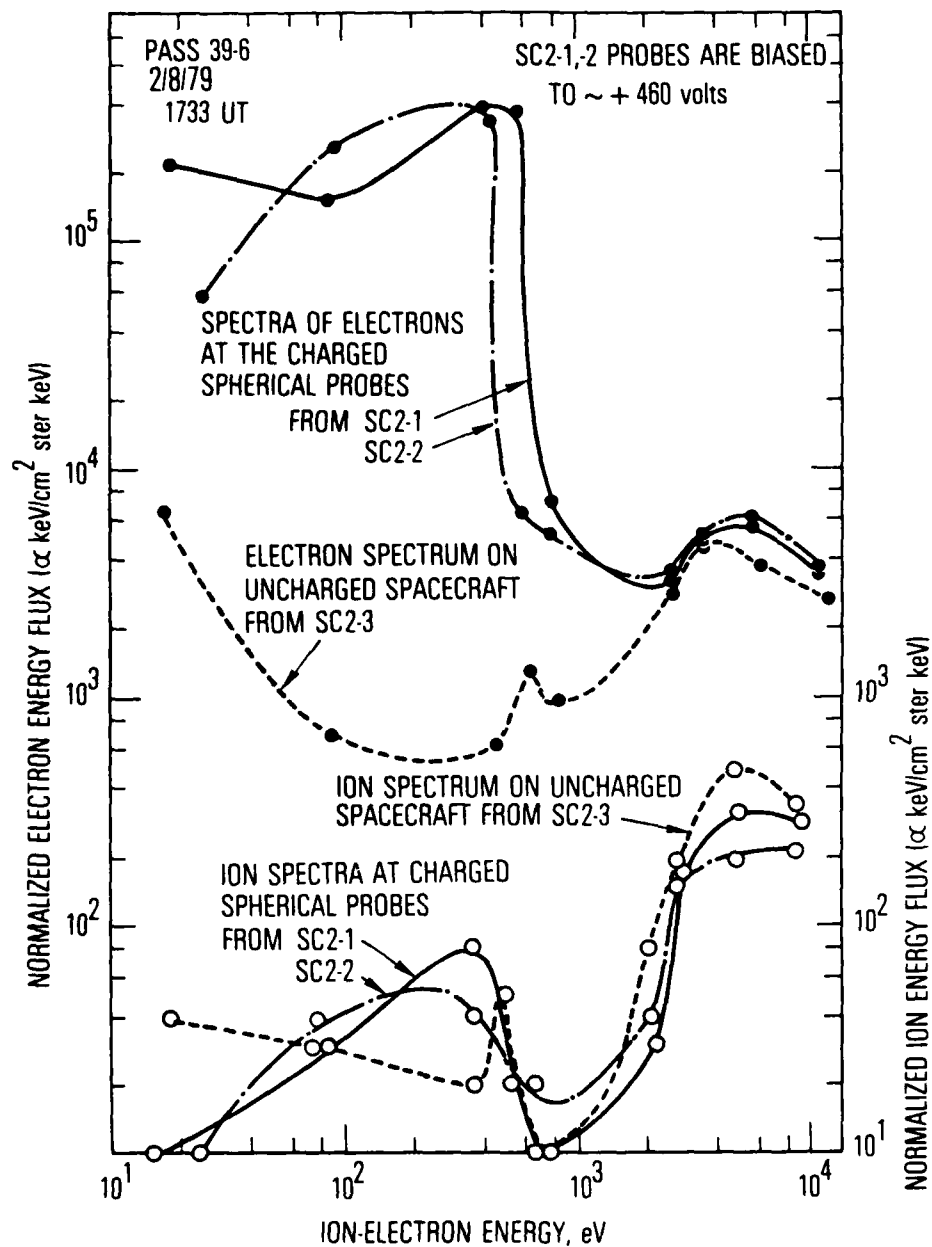


Fig. 4. Electron and Ion Energy Flux Spectra as Measured at SC2 Probes and on Spacecraft (SC2 probes are biased +460 volts relative to spacecraft ground)

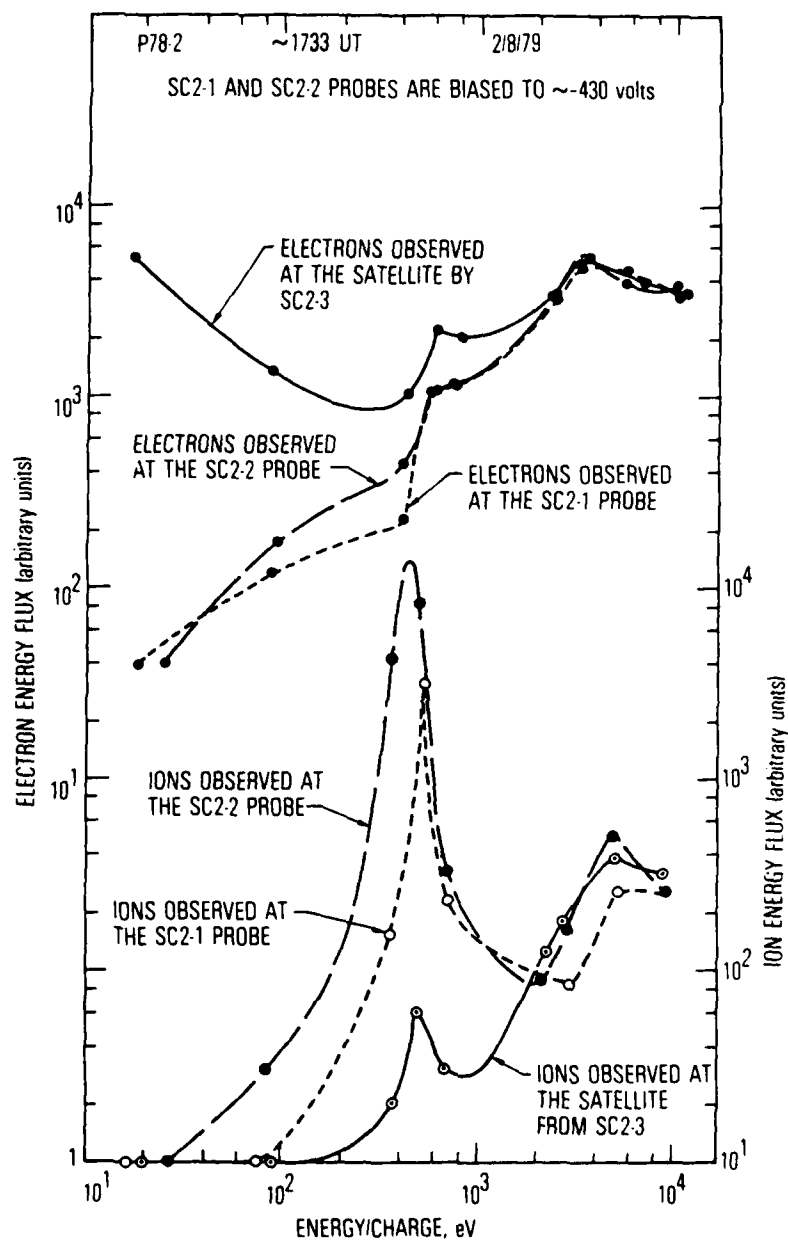


Fig. 5. Electron and Ion Energy Flux Spectra as Measured at SC2 Probes and on Spacecraft (SC2 probes are biased to -430 volts relative to spacecraft ground)

Figure 6a shows another example of particle acceleration by a charged body in the plasma. Two sets of ion and electron differential energy flux spectra, from the SC2-3 on the spacecraft, are shown. The \bullet points show the ambient particle spectra observed prior to artificial charging of the spacecraft. The \circ points are the spectra observed after the spacecraft has been charged to $V_s \sim -430$ volts by emission of ions from SC2-4. The ambient cold-ions are accelerated to the spacecraft and show up as a "charging spike" in the ion spectrum with a peak at an energy equal to V_s . The electron fluxes are noticeably depressed over a wide range of energies. Figure 6b shows the same data in spectrogram format.

If one integrates over the "charging spike" in the ions then one obtains an estimate of 1.4 cm^{-3} for the cold ion density. (When the SC9 [San Diego particle spectrometer, S. DeForest principal investigator] data becomes available it can independently estimate the cold plasma density with somewhat greater precision.) The number obtained is reasonable for the region of space in question (Altitude ~ 31840 km local time ~ 1.6 hr, $L \sim 6.4$).

We have, for completeness, added the energetic proton data from the SC2-6 telescope to Figure 6. The fluxes have been plotted on an absolute basis using the geometric factor in Table 2. The SC2-6 data are the points with the horizontal bars. The bars denote the width of each channel in energy. The point is plotted at the central energy. There is very good agreement between the electrostatic analyzer points and those from the energetic proton detector. Thus, between these two instruments we can characterize the ion distribution from ~ 20 ev to ~ 3.3 MeV.

Figure 7 shows another observation during an artificial charging event. The spacecraft was charged to $\sim +500$ volts by using the onboard electron accelerator (SC4-1, H. Cohen principal investigator). The SC2-1 spherical probe was grounded to the spacecraft frame and thus is also at $+500$ volts relative to the plasma. The electron

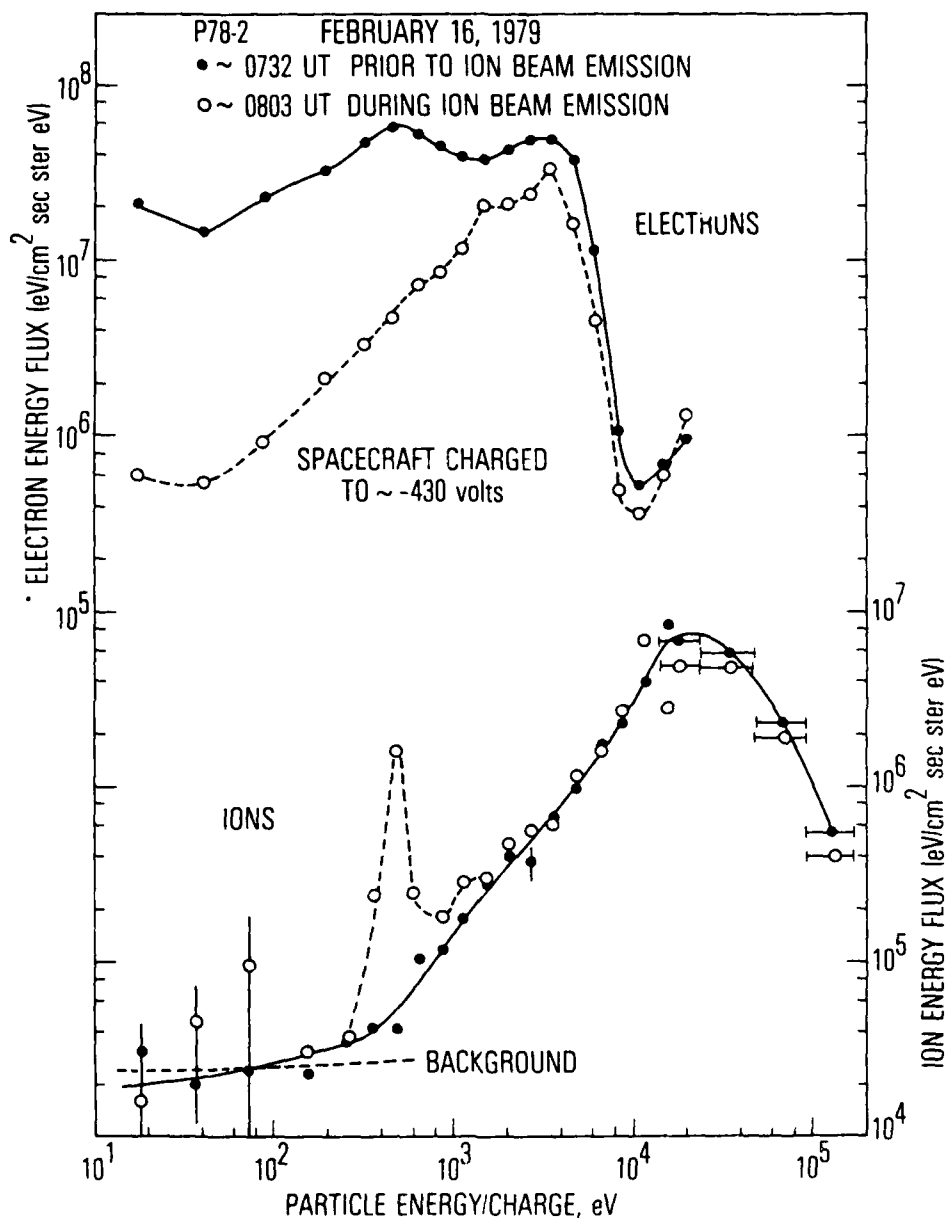


Fig. 6a. Electron and Ion Energy Flux Spectra at Spacecraft Both Before and During an Artificial Charging Event (Spacecraft was charged to ~ -430 volts relative to the plasma. The points with bars are from the energetic ion detector.)



Fig. 6b. Electron and Ion Energy Flux Data from SC2-3 and SC2-6 Instruments in Spectrogram Format During an Artificial Charging Event on 16 February 1979 (The trace below the spectrogram is a plot of the SC2-1 probe voltage measurement during the charging event.)

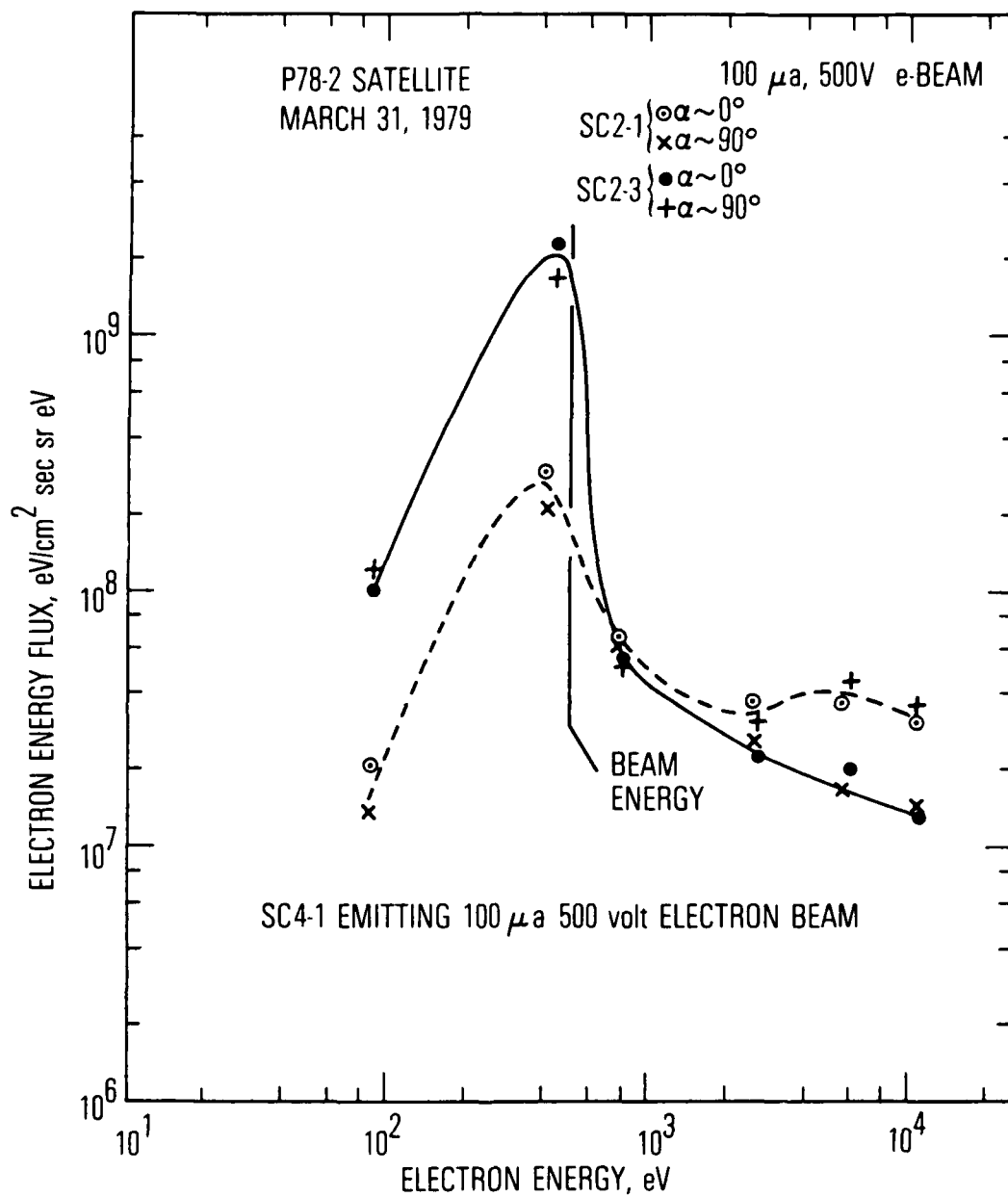


Fig. 7. Electron Energy Flux Spectrum at SC2-1 Probe and at Spacecraft During an Artificial Charging Event (The spacecraft was charged to ~500 volts at a time)

accelerator is relatively close to the SC2-3 particle analyzer, in the center band of the spacecraft, and pointed away from the SC2-1 probe. The SC2-3 analyzer is in the conductive center band but within about 25-30 cm from an insulated portion of the centerband and about 18 cm from the solar arrays which have nonconducting surfaces (ref. Fig. 1).

One would expect to see the ambient electrons accelerated to the spacecraft and probe. This is indeed observed as is evidenced by the peak in the observed electron spectra near the beam energy (not all energy channels are available yet for these data). Note that the flux to the analyzer on the spacecraft is about a factor of 8-10 higher than that observed by the boom mounted experiment. The spectral shapes and particle flux are essentially independent of pitch angle α . A very preliminary analysis by the SC5 and SC9 experiments showed that their measured fluxes are more consistent with those of SC2-1 (D. Hardy and S. DeForest, private communication; 1979). If this is true then the higher SC2-3 fluxes may represent a partial return of the electron beam to the conductive regions near SC2-3. It may also mean that the existence of the insulators close to SC2-3 sets up electric fields which focus the ambient electron currents to the center band in such a way that the returning flux is higher at SC2-3 than it is near the other instruments. A detailed analysis of these effects must wait until the data tapes are available for processing so that all experimental data can be brought to bear.

Figure 8 shows some very interesting angular distributions obtained by averaging data from five spin periods into 18 angular bins. The low energy ions are seen to peak along the magnetic field in both ($\alpha \sim 15^\circ$, $\alpha \sim 165^\circ$) directions while the more energetic ions range from isotropic to peaked perpendicular ($\alpha \sim 90^\circ$) to the field. These are some of the first if not the first observations (Geos I may have observed similar distributions but they are not yet in the published literature) of field aligned ions which are flowing both towards and away from the equator. The angular distribution of the ions along B is

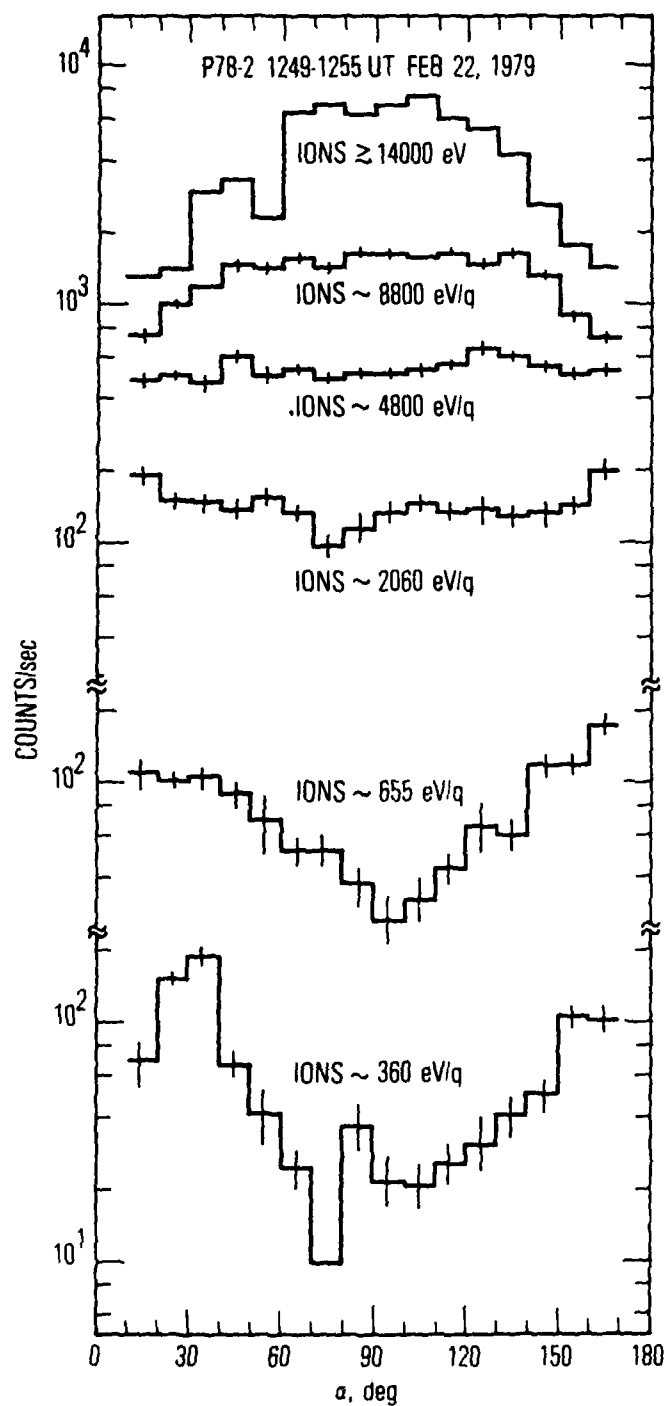


Fig. 8. Angular Distributions of Ions with Energies from 360 to 1400 eV (These distributions were measured at the spacecraft)

broad (i.e., $\sim 20^\circ - 50^\circ$ wide) at the half intensity point. Field aligned ions have been observed on these magnetic flux tubes ($L \sim 7$ in dipole field model) by low altitude satellites such as S3-3 (Ghillmetti et. al., 1978; Mizera and Fennell, 1977; Shelley et. al., 1976) in similar energy ranges but more usually tightly collimated. One would expect that if these are the ions from such a low altitude source that they would be much more highly collimated. If they are from a low altitude source then they have been pitch angle scattered as they moved up the field line toward the equator. Otherwise they were generated relatively high up and accelerated along the field line or represent a fresh injection. In any case, more analysis is required to ascertain their source and that is outside the scope of this report.

We have presented a brief survey of results from the P78-2 satellite. These are only a very small number of isolated measurements but they do hint at the kinds of data that will be available from this very exciting mission.

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